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ALPIDE: the Monolithic Active Pixel Sensor for the ALICE ITS upgrade

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Summary. — The upgrade of the ALICE vertex detector, the Inner Tracking System (ITS), is scheduled to be installed during the next long shutdown period (2019-2020) of the CERN Large Hadron Collider (LHC). The current ITS will be replaced by seven concentric layers of Monolithic Active Pixel Sensors (MAPS) with a total active surface of $\sim 10\,\mathrm{m}^2$, thus making ALICE the first LHC experiment implementing MAPS detector technology on a large scale. The ALPIDE chip, based on TowerJazz 180 nm CMOS Imaging Process, is being developed for this purpose. A particular process feature, the deep p-well, is exploited so the full CMOS logic can be implemented over the active sensor area without impinging on the deposited charge collection. The upgrade of the ITS presents two different sets of requirements for sensors of the inner and of the outer layers due to the signicantly different track density, radiation level and active detector surface. The ALPIDE chip fulfils the stringent requirements in both cases. This paper summarises the ALPIDE features and main test results.

1. – Introduction

A Large Ion Collider Experiment (ALICE) was designed to address the physics of strongly interacting nuclear matter, and in particular to study the properties of the Quark-Gluon Plasma, using p-p, p-Pb and Pb-Pb collisions at the CERN LHC. The ALICE apparatus is made of several sub-detectors, among which the closest to the colliding region is the Inner Tracking System (ITS), whose upgrade is necessary to improve the ability to detect heavy-flavour hadrons and low-mass dileptons emitted after the collision. The new ITS will consist of seven layers [1], three in the so-called "Inner Barrel" and four in the "Outer Barrel". All the layers will be populated by MAPS (Monolithic Active Pixel Sensors) [1]. The requirements for the sensors to be implemented for the Inner and Outer Barrel are listed in table I.

TABLE I. – *General pixel-chip requirements* [1] *and performance of ALPIDE sensor* [3].

Parameter (unit)	Inner Barrel	Outer Barrel	ALPIDE
Chip size (mm^2)	30×15		✓
Chip thickness (μm)	50	100	✓
Detection efficiency (%)	> 99		✓
Fake-hit rate* ($\text{pixel}^{-1}\text{event}^{-1}$)	$< 10^{-6}$		$\lll 10^{-6}$
Spatial resolution (μm)	5	10	≈ 5
TID rad. hardness** (krad)	2700	100	tested at 500
NIEL rad. hardness** ($1\,\text{Mev}\ n_{eq}\ \text{cm}^{-2}$)	1.7×10^{13}	10^{12}	✓

*Revised w.r.t. TDR [1].
**This includes a safety factor of ten.

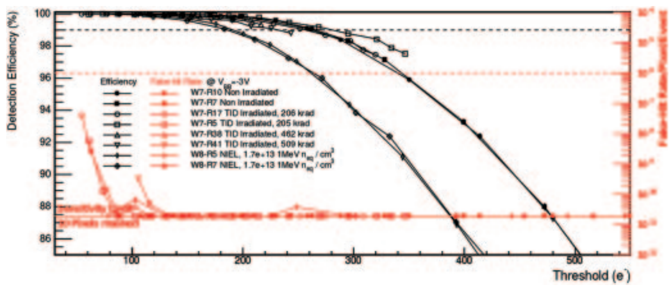

Fig. 1. – ALPIDE detection efficiency and fake-hit rate as a function of threshold.

2. – ALPIDE

ALPIDE (**AL**ICE **PI**xel **DE**tector) is based on the TowerJazz 180 nm CMOS imaging process and is produced on wafers with a high resistivity ($> 1\,\text{k}\Omega\,\text{cm}$) $25\,\mu$m p-type epitaxial layer on a p-type substrate. A single chip contains half a million pixels distributed in 512 rows and 1024 columns. In-pixel circuitry features amplification, shaping, discrimination and multi-event buffering [2]. A brief overview of the ALPIDE performance is shown in table I. ALPIDE design has been validated in an extensive test-beam campaign by measuring the detection efficiency, the fake-hit rate, the spatial resolution and the radiation hardness of the chip.

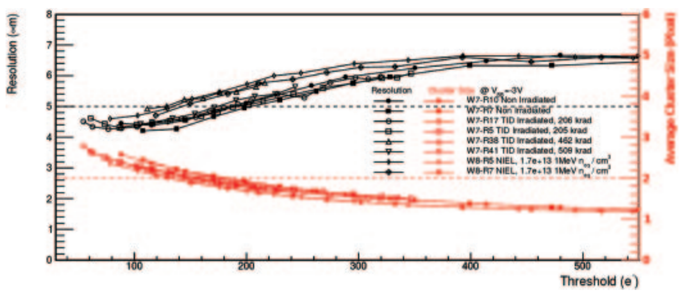

Fig. 2. – ALPIDE spatial resolution and cluster size as a function of threshold.

The impact of irradiating ALPIDE with protons and neutrons on detection efficiency and fake-hit rate is shown in fig. 1. The NIEL fluence of 1.7×10^{13} $1\,\mathrm{MeV}\ \mathrm{n_{eq}}\,\mathrm{cm}^{-2}$ has no effect on fake-hit rate while the detection efficiency is reduced. It is still possible to operate the sensor with efficiency higher than 99% for a wide range of threshold settings.

The spatial resolution, before and after irradiation is shown in fig. 2. It can be observed that even after receiving the full non-ionising radiation dose expected during the detector lifetime in ALICE, including a safety factor of ten, the detector can be operated with a spatial resolution smaller than $5\,\mu$m.

3. – Conclusion

ALPIDE is the state of the art MAPS to be installed in the new ALICE ITS. The performance of ALPIDE meets the upgrade requirements, including radiation tolerance at least up to the total dose foreseen during the exploitation lifetime of the detector.

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